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INTERACTIONS BETWEEN FIRMS AND UNIVERSITIES IN BRAZIL: a Historical Perspective

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ABSTRACT:

The interaction between firms and universities in Brazil is very weak. Successful "points of interaction" between science and technology are scarce and localized. This paper investigates the historical roots of this pattern of interaction. The hypothesis of this paper suggests that this pattern of interaction could be explained by the combination between, first, the late beginning of the formation of universities and research institutes (circa 1808) and, second, the historical backwardness of industrialization in Brazil. Furthermore, the successful points of interaction are products of long term processes of institutional building and systematic and persistent long term investments.

KEY WORDS: science, technology, interactions, late industrialization, historical perspective.

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Introduction

A reasonably consensual view found in the literature on the economics of technology relating to Brazil is that the national innovation system (NIS) is precarious and still at a relatively early stage of construction. The Brazilian innovation system can in fact be said to be at an intermediate level, possibly comparable to NISs of Mexico, Argentina, Uruguay, South Africa, India and China (see, for example, Viotti & Macedo, 2003).

This intermediate position of Brazil's innovation system is noted by Mazzoleni & Nelson (2007) in an article whose main aim is to discuss the role of research institutions in "catching-up" processes and successful examples of linkages between research and firms and economic activities in general (taken from Japan, South Korea and Taiwan). In the Brazilian case, they focus on a discussion of two specific experiences: agriculture, centering on Embrapa; and aircraft manufacturing, embodied by Embraer. The Brazilian experience is contrasted with those of Korea and Taiwan, and the Brazilian position is classified as intermediate.

One of the characteristics of innovation systems in this intermediate position is the existence of research and education institutions that are in place but have not yet succeeded in mobilizing contingents of researchers, scientists and engineers in proportions comparable to those of the most developed countries.

Similarly, the involvement of firms in innovative activities is still relatively limited. This in turn restricts an important component of well-developed innovation systems, which is strong linkages between business and universities, enabling the latter to serve as positive feedback circuits between the scientific and technological dimensions.

Hence a reasonable diagnosis of Brazil's situation under this heading would indicate the existence of a "pattern of university-firms interaction" characterized only by localized "points of interaction" between the scientific and technological dimensions. Rapini (2007) identifies this localized and scattered configuration in successful cases of linkages between universities and/or research institutions, and firms. A description of these cases (e.g. Paula & Silva, 2007; Morel, 1999) contributes to an understanding of the historical origins of the institutions and the interaction process that structures the linkages concerned.

Generally speaking, a long historical process of learning and accumulation of scientific knowledge and technological competencies involving significant linkages between productive effort, government, and research and education institutions lies behind all Brazilian products with comparative advantages in the international market. The most important of these include the following, with the respective knowledge areas and research institutions involving interaction':

(1) in health sciences — production of serums and vaccines (Oswaldo Cruz Institute, Butantan Institute);

(2) in agrarian sciences — cotton, forests for paper pulp, grains, meats (IAC, Embrapa);

(3) in mining, materials engineering and metallurgy — production of ores, steels and special metal alloys (UFMG);

(4) in aeronautical engineering — aircraft production by Embraer (CTA and ITA);

(5) in geosciences — oil and gas production by Petrobras (COPPE-UFRJ, Unicamp).[3]

Despite the importance of these products and knowledge areas, it would be no exaggeration to say that the "pattern of interactions" identified is fairly limited and still insufficient to impart to the economy as a whole a dynamic of growth based on the strengthening of the nation's innovative capacity.

This article investigates the historical roots of the debility of the interactions between science and technology (or between universities and research institutions on one hand, and firms on the other) in Brazil. Our basic hypothesis is that this pattern of interaction could be explained by the combination of, first, the late beginning of the formation of universities and research institutes (circa 1808) and, second, the historical backwardness of industrialization in Brazil.

This pattern of interaction includes the existence of "points of interaction" which constitute successful cases of relationships between research institutions and universities on one hand and firms on the other. The existence of such cases and their limited number fuel a complementary hypothesis that the success of the cases identified in these "points of interaction" is based on long-term construction involving systematic efforts that persist over time. These historical roots also require investigation.

The article therefore explores a view of the linkages between science and technology that takes into account the importance of the passage of time for mutually reinforcing relationships between these two dimensions to mature. For this reason, the study falls under the heading of the economic history of science and technology, as suggested by Szmrecsányi (2000).

1. Three dimensions for an economic history of science and technology

To develop the idea proposed by Szmrecsányi (2000), it may be necessary to deal with three dimensions, not just science and technology, but also their sources of funding, which entails some kind of analysis of monetary and financial structures. Although this subject merits a theoretical and historical discussion too vast to come within the scope of this article, a few exploratory comments may contribute here to a deeper understanding of the conjectures mentioned in the introduction: as

[3] There are many other important instances, especially from the regional standpoint, such as the production of fuel alcohol in São Paulo State and Rio de Janeiro State and in the Northeast; electric motors and turbines in Santa Catarina, with the Federal University of Santa Catarina (UFSC) playing an important role; and cocoa processing and textile manufacturing in Bahia, supported by the Institute of Industrial Chemistry, successor to the Bahia Institute of Agriculture (founded in 1857), among others. The article does not discuss these regional cases, or oil and gas production, but they will be covered by regional studies.

discussed in Section 3 below, the lagging process of university and research institution building, alongside the lateness of Brazilian industrialization, also combine with the backwardness arising from the relatively recent creation of monetary and financial institutions in Brazil.

One of the most striking elements in world history is the coincidence, correlation or geographical juxtaposition between scientific and technological leadership and the leading region's position in terms of accumulated monetary and financial resources. However, care is of course required to avoid mechanistic associations and develop appropriate mediations and qualifications.

On an initial level, the vast historical panel elaborated by Braudel (1979; 1986) provides a secure introduction to this articulation. Braudel argues for the existence of multiple "world-economies", each with its own hierarchy and center. In the third volume of *Civilization and Capitalism* (entitled "The Perspective of the World"), Braudel traces the development of the European world-economy and the "world-cities" that successively ruled it: Venice (1378-1498), Genoa (1557-1627), Amsterdam (1585-1773), and London (1773-). Albeit outside the scope of his book (which stops at 1800), on many occasions he suggests how the sequence continues, with New York taking London's place in the 1920s.

The relations between these three dimensions can be inferred from a topic in the exposition of G. Arrighi, who identifies an analogy between the Italian and Dutch patterns, in the shape of "surplus capital utilization for investment in the conspicuous consumption of cultural products through the patronage of the arts and other intellectual pursuits". According to Arrighi (1994, p. 139), "just as fifteenth-century Venice and Florence had been the centers of the High Renaissance, so early seventeenth-century Amsterdam became the center of the transition from the 'climate of the Renaissance', which had pervaded Europe in the preceding two centuries, to the 'climate of the Enlightenment', which was to pervade Europe in the next century and a half".

On a second level of analysis, it is possible to identify in the work of a historian of technology with the quality of J. Mokyr fairly early signs of linkages between universities and important economic activities. During the Renaissance, a period of history during which economic and financial hegemony was located in the Italian city-states, Mokyr highlights as one of the achievements of science and technology the onset of the application of mathematics to engineering. Among other applications, notes Mokyr (1990, p. 74), "[i]n the fifteenth century, Italian mathematicians showed how navigation could be aided by mathematics and Venice created a university chair of mathematics devoted to navigation".

Along the same lines, Freeman (1999, p. 150-151), in an interesting historical overview of innovation systems, refers to the industrial and technological leadership of Venice (stressing its leadership in finance) and notes that important institutions were created in the Italian city-states, including the first universities and the first system of patents (Venice, in 1474).

On a third level of analysis, it is possible to identify this three-dimensional articulation by focusing on a key individual in the scientific revolution. Galileo was supported among others by the Medici, the leading bankers during that period. Galileo produced horoscopes for the Medici (Reale et al, 1986, vol. II, p. 199).[4] He studied and researched in Padua, Venice and Florence. His skill in instrumentation enabled him to develop a powerful telescope; indeed, he supplemented his salary as professor of mathematics at the University of Padua by making and repairing scientific instruments (Mokyr, 1990, p. 73). Moreover, the technical means to produce special lenses were available in the city where he lived, then an important glass manufacturing center (Ravetz, 1990, p. 210). In a account of the improvements introduced into mining during and after the Renaissance, Mokyr locates demands presented by this sector to the scientists of the time: "[t]he greatest minds of the seventeenth century, from Galileo to Newton, were concerned with problems of air circulation, safety, pumping, mineralogy and assaying, and the raising of coal and ore from the mines" (1990, p. 64).

On a fourth level of analysis, a more recent case suggests that it is possible to identify a link between the characteristics of finance (public and private) in the United States and the evolution of its industrial and scientific structure.

In formulating his concept of the "Long Wave from 1787 to 1842", Schumpeter (1939) discussed the role played by the creation of credit and other contributions peculiar to the industrialization process then under way: "[i]n the United States profits and the *ad hoc* creation of means of payment were obviously the main domestic sources of the 'funds' which financed industrial and other enterprises" (p. 195).[5] He then suggested a role for the daring banking practices of the period: "[i]t was the financing of innovation by credit creation – the only method available, as we have seen in the course of our theoretical argument, in the absence of sufficient results of previous evolution – which is at the bottom of that 'reckless banking'. This undoubtedly sheds a different light upon it. Those banks filled their function sometimes dishonestly and even criminally, but they filled a function which can be distinguished from their dishonesty or criminality" (p. 197).

As for public finance, a number of changes made to the U.S. financial system during the New Deal (when the U.S. was consolidating its world economic and financial leadership) can be considered a precondition for the architecture of the innovation system built during and after World War II. The strengthening of public finance through the fiscal and tax-raising hegemony of the central government certainly created one of the foundations for the significant federal public spending on R&D that was to distinguish the U.S. in the 1950s and 1960s, especially for basic science (Nelson & Wright, 1992).

[4] When Galileo discovered Jupiter's moons, he originally named them Cosmica Sydera in honor of Cosimo de' Medici. He later opted for Medicea Sydera, honoring all four Medici brothers.
[5] For a discussion of monetary innovation in the United States, see Sylla (1982).

In sum, addressing all three dimensions (money-finance, science, and technology) is most important in the economic history of science and technology. Once again, it is necessary to allude to Braudel, who explores the relations between money and technique (1986, p. 81) and emphatically notes the role of finance in the English industrial revolution.

2. Historical roots of university-firms interaction in developed innovation systems

The notion of a national innovation system derives from the evolutionist or neo-Schumpeterian approach: it expresses the complex institutional arrangement that drives technological progress and by so doing determines the wealth of nations (Freeman, 1995). The NIS concept was developed by scholars who consider history an important element (Freeman, Nelson and Rosenberg, among others). Freeman (1995), for example, locates and discusses the emergence and historical development of specialized research and development (R&D) activities, an institutional innovation introduced into Germany in 1870: this argument presented by Freeman can be considered a suggestion for a research agenda in which history is decisive.

The development of an economic history of science and technology, therefore, would contribute a great deal to our understanding of the historical roots of innovation systems. This theoretical dialogue is one of the motivations for the present article.

To some extent all the most important research into innovation systems takes into account the historical roots of the process of building the relevant institutions. The collection of essays edited by Richard Nelson (1993) is an excellent example. All 16 studies of experiences in different countries include detailed descriptions and analysis of the origins and historical development of the institutions that make up the various innovations systems concerned. These case studies, particularly those on the U.S., Japan, Germany, Sweden and Denmark, provide a wealth of examples of persistent traditions, path dependence and evolutionary processes grounded in historically relevant efforts. As a result it is not hard to see the relevance of assessing the history of how the institutions that make up these systems, especially research institutions, universities and firms, were built.

Unfortunately one of the main weaknesses of the evolutionist approach is precisely its failure to examine in depth how monetary and financial systems are linked with the construction of innovation systems. In a critical review of the literature, O’Sullivan (2004) highlights this significant lacuna in innovation economics and proposes a dialogue between researchers in this field and financial historians to fill the gap.

Having noted this important limitation, we can nevertheless move on to ask what the literature has to say about the interactions between science and technology in well-developed national innovation systems (NISs).

Nelson & Rosenberg (1993, p. 5-9) point to the intertwining of science and technology as a key feature of NISs. They sum up the complex interactions between these two dimensions by saying that science is both a "leader and follower" of technological progress. Evidence of this dual role can be drawn from the literature.

Rosenberg (1982) presents the role of technology as: (1) a source of questions and problems for scientific endeavors; (2) an "enormous repository of empirical knowledge to be scrutinized and evaluated by scientists" (p. 144); (3) a contribution to formulation of the "subsequent agenda for science" (p. 147); and (4) a source of instruments and research equipment etc. Rosenberg concludes that "powerful economic impulses are shaping, directing and constraining the scientific enterprise" (p. 159).

To look now at the flow in the opposite direction, Klevorick et al (1995) present empirical evidence about the role of universities and science as an important source of "technological opportunities" for industrial innovation. Their study shows how different industrial sectors rank the relative importance of universities and science to their innovative capabilities.[6]

Rosenberg (1991) asks "why firms do basic research" and suggests it is an "entry ticket to a network of information". This point relates to the discussion in Cohen & Levinthal (1989) about the two sides of R&D, innovation and learning, stressing the importance of investment as a way to develop "absorptive capability".

Narin et al (1997) find empirical evidence for the "increasing linkage" between science financed by the public sector and industry in the U.S. A recent OECD study describes the "intensification of science-industry relations in the knowledge economy", stressing that "links with science are more important than in the past" (OECD, 2002, p. 16).

Finally, Rosenberg (2000) suggests U.S. universities differ from those of other (developed) countries "in the greater speed and greater extent of their response to changing economic circumstances" (p. 36). He notes five distinctive features of U.S. universities: (1) the ability to respond to the economic needs of society ("economic responsiveness"); (2) a high degree of decentralization; (3) close connectedness between universities as well as intense competition (for resources, especially financial support); (4) the size of the university system ("its great size, in contrast to any of the European countries, is important because it has made it possible to maintain a high degree of specialization and diversity within a large system", p. 41); and (5) a unique synthesis of advanced research with graduate and professional education (p. 42). Rosenberg's analysis helps show the importance of the size of a university system in enabling it to respond quickly to economic

[6] Klevorick et al. show why firms monitor and follow developments in the universities. Significant knowledge streams flow from scientific institutions to the industrial sector, particularly high-tech industries.

requirements, as may perhaps be more clearly presented in Klevorick et al (1995), Narin et al (1997) and Cohen et al (2002).

These studies underscore the relevance of these two dimensions of innovative activities, stressing the division of labor between them, supporting an understanding of the strong and mutual feedback between science and technology in developed countries, and indicating an intensification of these linkages. Thus the literature suggests that these relationships need to function for modern economic growth to be feasible.

These studies focus strongly on the case of the United States. It is not difficult to show how the institutions and dynamics of interaction have been built up, as discussed in the above-mentioned texts. Work by such researchers as Rosenberg (1972 and 2000), Nelson & Wright (1992) and Nelson & Rosenberg (1994) describes important aspects for an understanding of this long construction process.

The question addressed by this article can now be formulated more specifically: A long historical process is required to build these linkages and interactions. At least five elements (which depend on investment and time for development and maturation) can be indicated: (1) preparation of the monetary and financial arrangements to make feasible the creation and functioning of universities/research institutions and firms, among other elements; (2) construction of the relevant institutions (universities, research institutions, firms, and their R&D laboratories);[7] (3) construction of mechanisms to enable these two dimensions to interact (problems, challenges etc. that induce at least one of the two sides to seek out the other and attempt to establish a dialogue); (4) development of interactions between the two dimensions (learning processes, trial and error etc); and (5) consolidation and development of these interactions, involving an explicit recognition of the role played by time to build mutually reinforcing relationships (positive feedback) between research institutions/universities and firms (as could be derived from the literature reviewed above).

3. The first innovation system institutions in Brazil

A preliminary comparison between Brazil and the United States at the time of independence is enlightening: in 1822, with a population of 4.5 million, Brazil had no universities (Cunha, 1980), while in 1776, with 2.5 million inhabitants, the U.S. had nine universities (Maddison, 2001).[8] Even in comparison with other Latin American countries, Brazil made a very late start on setting up universities. According to Schwartzman (1979, p. 54), “in institutional terms science in Brazil

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[7] The construction of these institutions presupposes in turn that progress has been made in terms of an opening to absorb advances in scientific and technological thinking. For example: Carvalho (1993, p. 86) mentions an edict of the Rector of the Coimbra College of Arts (May 7, 1746) prohibiting the teaching of Descartes and Newton. The Pombaline Reforms were an attempt to change this situation.

[8] To emphasize the importance of universities to development processes, it is worth comparing Germany in the 1870s, with 16 universities, and England, with only five (Blackbourn, 2003, p. 207). The history of the late nineteenth century shows Germany overtaking England in industrial, technological and scientific terms.

lagged far behind science in Spanish America until the second half of the eighteenth century ... Fearing the establishment in Brazil of institutions that could rival those of Portugal, the Crown prevented the creation of a university ...”.

Although several medical, law and other schools of higher education were founded after 1808, when the Portuguese Court moved to Rio de Janeiro, no attempts to set up universities were made until the 1920s and, according to the literature on the formation of the Brazilian scientific community, the first full-fledged university created in Brazil was the University of São Paulo (USP), founded in 1934 (Schwartzman, 1979), by which time the population had passed the 30 million mark. Cunha (1980) mentions the existence of “successful universities” as opposed to “transient universities” in the 1920s: the University of Minas Gerais and the University of Rio de Janeiro.[9] Cunha’s book is appropriately entitled *Universidade Temporã* (“The Latecomer University”).

These latecomer universities, however, resulted from a process of institution-building that had begun a long time ago. For example, when USP was founded it incorporated the Polytechnic (founded 1894), the School of Pharmacy (1898), the School of Medicine & Surgery (1912), the Institute of Veterinary Medicine (1919), and the Biological Institute (1924), among others.

At the turn of the century there were, “according to Fernando de Azevedo, only six institutions in connection with which one could speak of a scientific spirit and a taste for experimentation, and only one of those could be considered directly part of the university sphere” (Schwartzman, 1979, p. 139). The institutions in question were these: the Paraense Museum, the Campinas Institute of Agronomy (IAC), the Paulista Museum, the Botanical Gardens, the Manguinhos Institute, and the Bahia Medical School. One of the characteristics of the science “that was institutionalized” in twentieth-century Brazil was its location “outside the higher education system” (p. 136).

If the creation of universities in Brazil began at the earliest in the 1920s, when did scientific research begin, given that it was conducted “outside the higher education system”? Until the late nineteenth century there were some scientific research activities in mineralogy, chemistry, natural sciences, agronomy, and zoology, as well as studies of bacteriological and microbiological problems, but they were limited in nature and sparsely distributed in institutions such as museums – particularly the Imperial Museum (1818), later renamed the National Museum, the Paraense Museum (founded in 1866 as the Archeological & Ethnographic Museum of the Philomathic Society of Pará, later renamed the Goeldi Museum), and the Paulista Museum (1893) – and research institutions such as IAC (1887), the São Paulo Vaccinogenic Institute (1892), the São Paulo

[9] According to Schwartzman (1979, p. 418), while the creation of the University of Rio de Janeiro in 1920 merged the Medical School, Polytechnic and Law School, “it changed practically nothing in the way the schools functioned”.

Bacteriological Institute (1893), and the Butantan Serum Therapy Institute (1899).[10] However, one of the major milestones in Brazilian scientific history was the creation of the Manguinhos Institute in 1900, with Dr Oswaldo Cruz as its key personage. Cruz was a graduate of the Rio de Janeiro Medical School and studied at the Pasteur Institute in Paris from 1896 to 1899 (Stepan, 1976, p. 69-73).

The school from which Cruz won his degree in medicine was founded in 1808, after King João VI came to Brazil. The arrival of the Portuguese Court led to significant changes including the creation of institutions such as anatomy and surgery courses in Rio de Janeiro and Salvador, the Botanical Gardens (1808), and the Military Academy (1810), which implicitly taught engineering (Cunha, 1980; Schwartzman, 1979). According to Cunha (1980, p. 69), "restructuring and expansion of higher education in Brazil after 1808 moved the study of mathematics, physics, biology and mineralogy out of philosophy courses, controlled by the Church, and into medical courses and the Military Academy, and much later to the Polytechnic when it split off from the latter".

The creation of these institutions between 1808 and 1810 can be considered the "first wave of research and education institution building" in Brazil. It is worth stressing the long gap in time between the creation of these institutions and that of the first universities: more than a century elapsed between one and the other. This explains the phrase coined by Schwartzman (1979, p. 81), who says science and higher education "vegetated" in the nineteenth century in Brazil.

Having located the "first wave of institution building" in Brazil in the period 1808-10, we have identified the late onset of the creation of a science and technology system properly speaking. It was not only late but also limited, since science and higher education merely vegetated during the nineteenth century, not to mention the fact that they were entirely separate from the rest of the nation's cultural and social life, although as discussed in the next section there was to be a second wave before the century was out.

As the introduction to this article suggests, this late onset was closely related to economic stagnation and to Brazil's colonial status until 1808, with the (perhaps consequent) absence of monetary institutions. According to Peláez & Suzigan (1976, p. 38), until the arrival of João VI monetary institutions "did not exist in Brazil, and there was nothing that could be called a paper currency". Gold, silver and copper had hitherto comprised the only means of payment circulating in Brazil.

The situation in 1808 can be characterized as a combination of restrictions imposed by the metropolis on manufacturing in the colony, a lack of higher education institutions, and a lack of

[10] See Schwartzman (1979, Appendix 1 – Timeline of Brazilian Science, 1500-1945, by Tjerk Guus Franken); and Sanjad (2006) specifically on the Goeldi Museum.

monetary institutions. In other words, until 1808 the triad discussed in Section 1 (money, science and technology) was practically non-existent in Brazil. After the arrival of João VI, institutions relating to the triad were created (Banco do Brasil, higher education institutions) or permitted (repeal of the ban on manufacturing).

Finally, besides being late and limited, the onset of institution building took place under adverse conditions, given the presence of slavery. Freyre (1990) discusses the relations between “slaves, animals and machines” in his book on Brazil during the sojourn of João VI (Chapter 10), describing how slavery contributed to the persistence of human traction in Brazil at a time when Western Europe and the U.S. were embarking on the transition from draft animals to steam traction (p. 527). Slavery was a major barrier to technical progress: “there is one great cause that prevents the adoption of machinery in abridging manual labour, as so many persons have an interest in its being performed by the slaves alone”, noted an English observer cited by Freyre (1990, p. 533).

Moreover, the inequality of the colonial economy determined by slavery is a key historical reason for the polarity between “modernization and marginalization”, defined by Celso Furtado (1987) as a structural feature of Brazilian economic growth and underdevelopment in general. This polarity and the “inadequacy of technology” also identified by Furtado help explain the structural persistence of inequality in Brazil and suggest questions for evaluating their impact on science and technology (restriction of resources for and interest in the generalization of basic education and elimination of illiteracy, as well as preservation of the elitist nature of higher education, with significant consequences in terms of lack of critical mass to trigger positive feedback processes between science and technology).

Furtado’s emphasis on social problems can also be seen in his argument that the success of South Korea and Taiwan owes much to social homogenization. In the Brazilian case, the modernization-marginalization polarity imposed a dynamics of growth that systematically reproduced exclusion, thus preserving and at times even intensifying social inequality.

In short, the discussion in this section shows that research and education institution building in Brazil began late, was limited in scope and problematical in nature because of the adverse conditions under which it took place.

4. “Waves” of research and education institution building

Having identified the late onset, limited scope and problematical context of research and education institution building in Brazil, we proceed in this section to suggest a periodization in successive “waves”. The discussion covers higher education institutions, research institutions, and institutions that coordinate or manage public policy in science and technology. The following paragraphs offer a general outline of the historical process of institution building and its conditioning factors.

The colonial period to 1808 can be considered a long epoch during which Brazil's autonomous development remained blocked. The colonial system was a lasting obstacle to scientific accumulation for the future nation. Paula (1988) and Novais (1979) show how the mechanisms of colonial domination operated to block economic progress in general. Within this overall blockage, specific measures affected the accumulation of scientific knowledge in Brazil. To take only one emblematic example, books were not allowed freely into the colony until 1821.

In addition to determining the late onset of the scientific accumulation process, the legacy of the colonial period includes countless problems that were to become major deficiencies and obstacles to development. The consequences of slavery have been analyzed by Sérgio Buarque de Holanda (1991, p. 25), Alfredo Bosi (1993, p. 146) and Roberto Schwarz (1991, p. 15). Holanda (p. 50-51) shows how "intelligence [was cultivated] as an ornament" rather than as an "instrument of knowledge and action". Schwarz refers to the "misappropriation of modern ideas" in the initial period after Independence, blaming the local elite for "oligarchic appropriation of progress on the plane of ideas" (1991, p. 139). The long-term influence of these problems on the process of scientific accumulation should not be underestimated, since they prevented the emergence of a climate that would have stimulated creativity, a free exchange of views, critical thinking, and experimentation, all of which are indispensable to scientific development.

As noted in the previous section, the "first wave of institution building" began after 1808. It included the creation of the first higher education institutions (anatomy and surgery courses in Rio de Janeiro and Salvador in 1808, and the Military Academy in 1810), as well as the Botanical Gardens and the National Library. The Rio de Janeiro Practical Chemistry Laboratory was set up in 1812 to "make solid soap" according to Schwartzman (1979, p. 63). The Royal Museum (renamed Imperial after 1822)[11] was founded in 1818 and later housed the first physics and chemistry laboratory (1824). Schwartzman (1979) locates in this period the first attempts to build a steel industry, including the Royal Iron Mill at Morro de Gaspar Soares, Minas Gerais, "created in 1808 as an official initiative" (p. 63).

A "second wave" can be said to have occurred between 1870 and 1900, comprising the Pará Archeological & Ethnographic Museum (1866), the Geology Commission (1875, dissolved in 1877 for lack of funds), the Ouro Preto Mining School (1875), the Experimental Physiology Laboratory, attached to the Imperial Museum (1880), the São Paulo State Geography & Geology Commission (1886), the Campinas Institute of Agronomy (1887), the Paulista Museum (1893), the São Paulo

[11] With the end of the Empire (1889), its name was again changed, this time to National Museum, and it became an important research institution.

Polytechnic (1894), the Vaccinogenic, Bacteriological and Butantan Institutes (1892-99), the Manguinhos Institute (1900), the Luiz de Queiroz Higher School of Agriculture (1901) (Stepan, 1976; Schwartzman, 1979), and the São Paulo Polytechnic's Materials Testing Laboratory (1899), a precursor of the São Paulo State Technological Research Institute (IPT), officially founded in 1934 (Motoyama, 2004, p. 206).

A "third wave" can be identified in the period 1920-34, when initiatives to create universities culminated with the foundation of USP in 1934. This was the "latecomer university" wave. The period is described by Cunha (1980), who distinguishes between "successor universities" and "transient universities". According to Cunha, "the first long-lasting higher education institution in Brazil with the term university in its name was the University of Rio de Janeiro, founded in 1920 after many failed attempts" (p. 212). Its creation involved a merger of Rio de Janeiro's Polytechnic with its Medical School and "one of its law schools" (p. 212). However, as mentioned above, the schools concerned continued to function independently (Schwartzman, 1979, p. 418). In 1927, the "technique of organizing universities by agglutination was emulated in Minas Gerais" (Cunha, 1980, p. 213).

The creation of USP in 1934 amalgamated existing schools with the newly founded School of Philosophy, Sciences & Letters. USP's foundation can be identified as the most important point in a broad process of endeavors, initiatives and articulations to build universities in Brazil, and as the creation of a new standard of quality which became a national benchmark from then on (Motoyama, 2004; Schwartzman, 1979). The education-research nexus was still weak, although there was already an awareness in some universities that a link had to be established.[12]

The fourth wave of institution building occurred in the post-war period. The Brazilian Center for Physics Research (CBPF) was set up in 1949 and the Aeronautics Technology Institute (ITA) in 1950, with the Air Force Technical Center (CTA) following shortly afterward. Two important coordinating institutions were set up in 1951: the National Research Council (CNPq) and the Higher Education Staff Development Office (CAPES). In the context of the period preceding the 1964 military coup, it is also important to note the creation of the São Paulo State Research Funding Agency (Fapesp) and the University of Brasília (UnB) in the early 1960s.

A fifth wave during the period of military rule can be identified. The highlights were the creation of research centers in the state-owned enterprises, including CENPE at Petrobras and CPqD at Telebras, and the foundation of the Brazilian Agricultural Research Corporation (Embrapa) in 1973. In addition, this period saw the creation of institutions and funds for the financing of science and technology, and of institutions to coordinate S&T policy, so that S&T

[12] As noted by Schwartzman (1979, p. 104), in the 1930s the Luiz de Queiroz Higher School of Agriculture attempted to build closer ties between teaching and research, especially in genetics, in collaboration with IAC, which in had begun a program of genetics applied to agriculture in 1928 (Schwartzman, 1979, p. 274).

development plans began to be formulated. In technology financing, the Technology Development Fund (Funtec) was set up in 1964 and administered by BNDES, the national development bank, which had been created in 1952. This fund gave birth to the National Technological Development & Innovation Agency (FINEP, 1965), which was to play an important role in coordinating government funding for S&T[13] and implementing university courses for graduates. Several Basic S&T Development Plans (PBDCT) were launched in the context of national development plans between 1972 and 1984, but they were only partially implemented and then abandoned in the 1980s with the advent of an acute economic crisis.

A noteworthy fact about coordinating institutions is that Brazil's Ministry of Science & Technology (MCT) was not created until 1985, with the end of the military regime. Until the mid-1990s the MCT faced serious difficulties, as indeed did all the institutions responsible for S&T funding and development, because of the weakness of the monetary and financial system, the third element in the triad mentioned in Section 1 above.

Although the monetary system grew as economic development gathered pace from the closing decades of the nineteenth century onwards, culminating in the creation of the Central Bank of Brazil in 1964, its structure evolved little. Private banks remained restricted to commercial lending. The demand for credit to finance industrial investment and S&T began to be met only after the federal government set up development agencies for this purpose, above all BNDES and FINEP in the 1950s and 1960s respectively. Endemic inflation kept the financial system and capital market underdeveloped until the mid-1990s, and this undoubtedly retarded still further the already lagging process of industrialization and, by extension, the process of scientific and technological development.

5. Identifying interactions between science and technology

To the belatedness and problematical nature of the process of institution building for the national innovation system must be added, also with negative connotations, the characteristics of the industrialization process, which placed limited and relatively unchallenging demands on the nation's scientific infrastructure.[14] The reasons are summarized below.

The adverse conditions bequeathed by slavery and their social and financial consequences led to lasting inequality, delayed the formation of a wage labor market, limited the size of the domestic market for goods and services, and created historical deficiencies in education and vocational training. All this had implications for the institution-building process discussed in

[13] Especially via the National Fund for Scientific & Technological Development (FNDCT).

[14] In his reading of the role of large enterprises in the industrialization processes of the U.S. and Germany, Chandler (1990) refers explicitly to the demands presented and met by education institutions in both countries, in contrast with Britain (for the U.S., pp. 82-83; for Germany, pp. 425-426).

preceding sections. Industrialization began in the late nineteenth century and continued in the twentieth under these selfsame adverse conditions, remaining subordinated to agriculture for export at least until the end of the 1920s. Thus industrialization was restricted throughout this period by the fact that demand from the hegemonic sector – and society in general – was limited. As a result, the demand for technological solutions was also limited.

In this environment the monetary and financial system also remained subordinated to agriculture for export, mainly to cater for its needs in terms of trade finance. Although industrialization benefited from the development of trade bill discounting, the benefits were limited because the financial system did not offer long-term credit for investment. Meanwhile, the government's position was ambivalent: it offered protection for certain industrial activities but at the same time cut budget allocations for programs designed to create capabilities in areas then considered strategic.[15]

The crisis in the export agriculture economy and the Great Depression radically changed the pattern of industrialization, which now focused on the domestic market. Industry began growing much faster, diversifying its production structure and receiving government support in the form of protection and, from the 1950s on, industrial policy. Industry's demands on the scientific infrastructure, albeit more sophisticated, remained relatively unchallenging until at least the end of the 1980s. This had to do with excessive protectionism, the domination of strategic industries by multinationals, lack of continuity in public policy, and recurrent macroeconomic crises.

In sum, these characteristics determined a predominant technological pattern that presented few demands to the scientific and university system. The universities remained limited to education. The combination of teaching and research began to be systematized only in the 1960s and 1970s, with the organization of graduate programs.

Despite all these difficulties, a few historical examples of linkages between the economy and research/education institution building are presented below to help develop the central argument of this article. Pressure of demands from the economy on the nature of scientific institutions is mentioned by Schwartzman (1979, p. 84): "new higher education institutions with a clear bias toward the productive sphere"; and Cunha (1980, p. 216): "applied research arose in Brazil in establishments created to address concrete and immediate problems", a passage where the author mentions IAC, the São Paulo Bacteriological Institute and the Manguinhos Institute, among others.

[15] Schwartzman (1979, p. 115-119) recounts an "attempt to implement chemistry" from 1919 when a private member's bill was passed to set up chemistry institutions and courses in industrial chemistry in various parts of the country. The program proceeded successfully until 1930, when the government cut off federal funding in response to economic crisis.

5.1. Health sciences

The health sciences are one of the world-class knowledge areas in Brazil today, especially in biomedical research for production of serums and vaccines. Two institutions have made a vital contribution to this achievement and are now internationally recognized for the production of both scientific knowledge, disseminated via the publication of articles in international journals, and serums and vaccines. They are the Butantan Institute in São Paulo and the Manguinhos Institute in Rio de Janeiro, later renamed the Oswaldo Cruz Institute and now Fiocruz. Both are more than 100 years old and are still renowned as centers of advanced research.

These two institutions were created between the late nineteenth and early twentieth century[16] to combat public health problems relating to endemic and epidemic disease, as well as epizootic disease (Schwartzman, 1979, p. 120-121). From serum and vaccine production they soon progressed to scientific research led by three of the first Brazilian scientists to acquire renown: Adolfo Lutz, Vital Brazil and Oswaldo Cruz. Publication of scientific papers drew attention from foreign scientists, who began to take an interest in the research they reported and in working in Brazil, as was the case in the ensuing decades. An important factor that influenced this trend was international recognition for the Manguinhos Institute in 1907, when it won a gold medal as first prize at the Fourteenth International Congress of Hygiene and Demography in Berlin (Schwartzman, 1979, p. 132).

The importance of these institutions, especially Manguinhos, is underscored by Stepan (1976), who locates the origins of Brazilian science in this context. It is also highlighted by Schwartzman (1979, p. 129), who describes how Manguinhos, set up to produce serums and vaccines, was transformed under the leadership of Dr Oswaldo Cruz into a center of education, research, technological development, innovation and biomedical service provision, a position consolidated more recently. As for Butantan, it has recently been rated the most important research institution in Brazil in terms of the mean number of citations per scientific article published.[17]

5.2. Agrarian sciences and forest engineering

Brazil's acknowledged international competitiveness in agricultural commodities and agribusiness is grounded not just in comparative advantages but also in a long process of research and education institution building in the field. The process began at the apogee of the coffee economy between the last quarter of the nineteenth century and the first three decades of the twentieth, advancing further in step with industrialization from the 1930s on.

[16] The Butantan Institute was officially created in 1901. It had been functioning since 1899 as the Serum Therapy Institute. Later it incorporated the São Paulo Bacteriological Institute, set up in 1892. The Manguinhos Institute was founded in 1900 as the Manguinhos Municipal Serum Therapy Institute.

[17] Study by Rodrigo Semeghini based on data from the Web of Science on citations between 2005 and 2007 of articles published in 2005 (*Folha de S. Paulo*, Oct. 28, 2007, Caderno Mais, p. 5).

During the period when coffee was hegemonic, demand from coffee growers led to the creation of a number of institutions directly and indirectly related to coffee activities starting in the late nineteenth century. These institutions played a significant role in the development of education and research in agrarian sciences during the twentieth century. According to Motoyama (2004, p. 213), they constituted a “complex of institutions designed to contribute to the performance of the agricultural sector” and were part, he argues, of an economic modernization project pursued by the coffee-growing elite. The most important were IAC (1887); the São Paulo Polytechnic (1894), which offered a course in agricultural engineering; the School of Practical Agriculture in Piracicaba (1901), later renamed the Luiz de Queiroz School of Agriculture (ESALQ); and the Coffee Defense Service (1924), set up to combat coffee pests and diseases and precursor of the Biological Institute for Agricultural & Animal Defense (1927), later renamed the São Paulo Biological Institute (Schwartzman, 1979, p. 422).

Some examples of the activities of these institutions in collaboration with the productive sector are illustrative. In the 1920s the São Paulo State Government launched a research program to improve cotton growing in the region. The aim was to produce cotton with longer fibers, which would fetch better prices and enjoy higher demand in the international market. The program was executed by a new department dedicated to cotton, set up in 1922 at IAC, and consisted of the selection of seeds and their distribution directly to growers, in accordance with rules laid down for IAC’s Cotton Section. A financial institution, the São Paulo Commodity Exchange (BMSP), was set up in 1917. Peláez (1972, p. 114-120) describes the links between IAC, BMSP, the government, the growers and industry. BMSP sent technicians abroad for training, and “while IAC was developing new cotton fibers, BMSP prepared the market for Brazilian cotton” (p. 117). According to Peláez (1972, p. 117), “it included most of the ingredients of modern technical assistance programs: development of research centers, technology transfer, financial knowledge, specialization abroad, and market development”.

IAC’s role in researching new varieties of cotton, selecting seeds and distributing them to growers had been supported by BMSP since 1919. Among other things BMSP created a Cotton Grading School in 1922 (p. 117). The positive results of this program benefited the textile industry, then the most important industry in Brazil, and encouraged more textile manufacturers to install production facilities in the state (Suzigan, 2000, p. 161).

Other cases of successful products in international markets also have historical roots, albeit less remote, involving interactions between government, research institutions and firms. These cases include paper pulp, grains and meat, among others.

In the case of pulp, in the 1930s the Brazilian government launched a program of tax incentives and financing for the development of local production. At the same time, several firms embarked on a research program to select seeds of plants considered best suited to pulp production. They set up laboratories and experimental plantations, employing agronomists and forest engineers recruited in Europe (Suzigan, 2000, p. 312-313). This was the first coordinated effort to promote a science-technology linkage for the production of paper pulp. It resulted in the selection of species that were later to produce eucalyptus pulp, the basis for Brazil's competitiveness in this industry. More recently, in the context of genomics projects developed in Brazil with public funding and participation by research institutions (including Embrapa, see below) and private enterprise from the pulp and paper industry, plant breeding research has been developed with the aim of increasing biomass productivity, disease resistance and forest output (Dal Poz, 2007, p. 153-155).

Agricultural production, in which Brazil enjoys ample competitive advantage on world markets, began to be revolutionized by Embrapa in the 1970s. Founded in 1973 to do R&D and transfer technology to farmers, Embrapa developed a large nationwide network of research centers and expertise in plant and soil sciences, genetic improvement, forest resources, environmental management, physiology, plant health, animal science, animal health, and animal nutrition and reproduction (Salles-Filho, 2000, p. 103). In the last three decades practically the entire agricultural sector in Brazil has benefited from the results of Embrapa's research transferred to producers of grain crops (soybeans, corn, sorghum, wheat), beef and dairy cattle, pigs and poultry, goats, cotton, fruit and vegetables, and forest products, among others. The organization's researchers adapt species to different types of soil and environment, introduce genetic improvements, create new plant varieties that are more productive and resistant to pests and disease, develop hybrids, introduce new production and crop management systems, and so on. More recently, of 13 subprojects comprising the Brazilian Genome Project coordinated by the Ministry of Science & Technology, Embrapa has participated in nine, with research on parasitic diseases, hog mycoses, development of more productive, nitrogen-fixing strains, plant growth promoters, fungal pathogens, the banana genome, and forest productivity, resistance and genetic improvement (Dal Poz, 2007, p. 153-155).

5.3. Mining, Materials Engineering & Metallurgy

The first business ventures in iron production date from the early nineteenth century, but it was not until the Ouro Preto School of Mines (EMOP) was founded that production began to increase in scale. The creation of EMOP was inspired by Emperor Pedro II's 1872 visit to the Paris School of Mines, which he used as a model, inviting a renowned French professor to head the future school in Brazil. Unveiled in 1876, EMOP exerted growing influence by training geologists, mining engineers and metallurgical engineers. Between the late nineteenth and early twentieth century, these professionals contributed to the creation of geographical and geological institutions and the mapping of iron ore reserves in Brazil. Their studies and research located and measured large reserves of high-content iron ore, and in 1910 their discoveries were presented at an international conference in Stockholm, attracting many foreign companies to develop the reserves (Schwartzman, 1979: Appendix; Suzigan, 2000: 274-75). Several projects bore fruit, giving rise to the first steel mills in Brazil in the 1920s. But the decisive boost was creation of Companhia Siderúrgica Nacional and Companhia Vale do Rio Doce during World War II, followed by public policy to accelerate industrialization in the post-war years.

However, one of the most important factors that explain the current success of Brazil's mining and steel industries is the rich experience of interaction between firms and the Department of Metallurgical & Materials Engineering at the Federal University of Minas Gerais (UFMG).[18] After creation of a graduate course in metallurgical and materials engineering by UFMG in 1973, its researchers discovered the industry's difficulties with imported technology and took the initiative of proposing collaboration with firms to diagnose the problems and offer solutions. The collaboration, funded by FINEP, started with the creation of technological extension courses and was later extended to include graduate programs run jointly by firms and the university. Between 1975 and 2006 the department awarded 256 master's degrees in metallurgical engineering to employees of 36 firms, and 20 PhDs to employees of ten firms, all in mining and steel production. Several of the master's dissertations and doctoral theses contributed important knowledge motivated by the search for solutions to concrete problems faced by firms, generating patents and technological innovations in processes and products.[19]

In addition to concrete results for the firms, this program of university-firms collaboration clearly demonstrates the importance of linking graduate courses to research; proves that teaching activities can also benefit from collaboration; and offers evidence that interactions can be prolonged indefinitely by the formation of interactive networks of researchers in firms and universities.

5.4. Aeronautical engineering

The position enjoyed today by Embraer (Empresa Brasileira de Aeronáutica) as one of the world's leading aircraft manufacturers results from a long history of efforts involving government, firms, and research and education institutions. It was founded in 1969, but since the 1930s the armed services and civilian experts alike had tried to persuade the government that Brazil needed an aeronautical industry as part of the industrialization process and national defense strategy (Forjaz, 2005, p. 281-282).

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[18] An impressive account of this experience has been written by one of its protagonists, Evando Mirra de Paula e Silva (Paula e Silva, 2007).

[19] Paula e Silva (2007) presents several concrete cases that illustrate the brilliant results achieved in technically elegant detail.

The first step, taken in the 1940s in the context of World War II, was creation of the Air Force Ministry to merge military aviation subordinated to the army and naval aviation into a single force. The project was designed from the start to assure mastery of aeronautical technology. As a result, well before aircraft production, an aeronautical engineering course was created at ITA and CTA was set up as a research center. Both were planned in late 1945. ITA began operating in 1948 on the premises of the Institute of Military Engineering (Rio de Janeiro) and was formally created in early 1950, when it was installed at São José dos Campos. CTA was set up shortly afterwards, with ITA formally subordinated to it (Forjaz, 2005: 290).

Thus the training of aeronautical engineers and mastery of aeronautical technology preceded creation of the industry. To assure a standard of excellence in these activities, agreements were signed with foreign institutions that sent scientists, researchers and professors while accepting Brazilian graduate students to study abroad. In 1961 ITA began its own graduate course, and a prototype of the Bandeirante aircraft designed and built at CTA flew in 1968. Embraer was founded in 1969. This was a pioneering experience in linkages between education, research and industry, with flows of people between Brazil and abroad contributing decisively to the industry's successful implementation. Analyzing this case, Forjaz (2005, p. 292) stresses that "native S&T development requires a relatively long maturation period and thus requires persistence and confidence in the future. However, it enables a domestic industry to offer the products that markets want and that are capable of surviving in a fiercely competitive international market".

6. Historical roots of interaction points

There are other cases, such as those listed in the introduction, but these four examples will suffice to provide an overview of the demands presented by the economy and society during some of the "institution-building waves" we have identified. More cases are described in Furtado (1982) who, in discussing the tensions created by the industrialization process under Vargas in the 1930s, mentions IPT's contribution to development of the cement industry (p. 21) and metallurgical industry (p. 23).

Even the creation of USP can be seen as linked to the industrialization drive beginning in the 1920s, based on certain highly utilitarian positions advocated in debates on the future university (Schwartzman, 1979, p. 192).

The successful cases mentioned throughout this article have clear historical roots: the case discussed by Paula e Silva (2007) certainly had its roots in EMOP; the Manguinhos Institute was crucial to the relatively successful control of Chagas disease described by Morel (1999); Embrapa and its contributions to Brazilian agriculture had took sustenance from initiatives such as IAC. The case of Embraer presented by Mazzoleni & Nelson (2007) has apparently more recent roots, anchored in the fourth wave of institution building that included the creation of CTA. In fact, Brazilian experience in aircraft production dates from as far back as 1906, with Santos Dumont (Motoyama, p. 191), and in the 1930s the military started to advocate the need for an aeronautical industry based on issues relating to territorial integration and the development of a nationwide airborne postal service.

In other words, the examples of successful cases do indeed indicate the importance of "long-term construction involving systematic efforts that persist over time", as stated by the hypothesis presented in the introduction.

Finally, the four cases described here contribute to an explanation of the historical roots of the scientific specializations that Brazil has today: medicine/health, agriculture, materials/metallurgy engineering, and aeronautics are major knowledge areas and/or scientific disciplines in Brazil.[20] This brief overview contributes to an understanding of the long construction process that has taken place in these areas.

7. Conclusions

This article, which is part of an ongoing research project, is only an introduction to a far broader research agenda. Many of the issues mentioned here require further investigation and development. This version merely contributes to the organization of some aspects of the historical roots of the existing pattern of interactions between universities/research institutions and firms in Brazil for later investigation.

The two hypotheses presented in the introduction can now be assessed from a better-informed point of view.

First, the late onset of research and higher education institution building is an important component for an understanding of the limitations of the existing NIS. As discussed, this onset was not only late but also limited (timid) and problematical (given the adverse conditions). An understanding of the nature of this onset helps discern more clearly the relationships between problems such as the pattern of income distribution today and the lack of aggressive public policies to eradicate illiteracy and universalize basic education, along the lines seen in Japan at the start of its industrialization process or in South Korea's and Taiwan's catching-up processes.

Second, by focusing on representative cases in which there is a clear linkage between social and economic demands and institution building it has been possible to confirm the hypothesis that the successful cases in Brazil's experience have solid historical roots. Some aspects of Brazilian

[20] The ISI scientific disciplines in which Brazil has the highest specialization ratings (with a specialization index greater 2.0) are as follows: (1) Agriculture/Agronomy, (2) Dentistry, Oral Surgery & Medicine, (3) Biology, (4) Entomology, (5) Medical Research & General Topics (ISI data for 2001). Geology and mining engineering rank eighth (with a specialization index of 1.526).

scientific specialization today are explained by the elements noted above in the development of health sciences, agrarian sciences, mining, materials and metallurgy, and aeronautical engineering.

Finally, to resume our dialogue with the idea proposed by Szmrecsányi (2000), the diagnosis outlined here that on one hand problems were caused by late onset and, on the other, the successful cases took a long time to mature strengthens the argument that S&T diffusion "from the center to the periphery of capitalism" faces considerable challenges, underscoring the importance of the variables time, effort, and political will (p. 406).

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REFERENCES

ARRIGHI, G. (1994) *O longo século XX*: dinheiro, poder e as origens do nosso tempo.Rio de Janeiro/São Paulo: Contraponto/Unesp (1996).

BLACKBOURN, D. (2003) *History of Germany, 1780-1918*: the long ninteenth century. Malden: Blackwell Publishing.

BOSI, A. (1993) *Dialética da colonização*. São Paulo: Companhia das Letras.

BRAUDEL, F. (1979, 1986). *Civilização material, economia e capitalismo*: séculos XV-XVIII. São Paulo: Martins Fontes, 3 v (Vol.1: A estrutura do cotidiano; Vol.2: Os jogos das trocas; Vol.3: O tempo do mundo). (1995-1996).

CARVALHO, L. R. (1993) A educação e seus métodos. In: HOLANDA, S. B. *História Geral da Civilização Brasileira*: a época colonial (administração, economia, sociedade), volume II, pp. 76-87 (7ª edição)

CHANDLER JR., A. (1990) *Scale and scope*: the dynamics of industrial capitalism. Harvard: Belknap.

COHEN, W.; LEVINTHAL, D. (1989) Innovation and learning: the two faces of R&D. *The Economic Journal*, v. 99, n. 397, p. 569-596.

COHEN, W.; NELSON, R.; WALSH, J. (2002) Links and impacts: the influence of public R&D on industrial research. *Management Science*, v. 48, n. 1, pp. 1-23.

CUNHA, L. A. (1980) *A universidade temporã*. Rio de Janeiro: Francisco Alves.

DAL POZ, E. (2006), *Redes de Inovação em Biotecnologia: genômica e direitos de propriedade intelectual*. Tese de Doutorado, Departamento de Política Científica e Tecnológica, Instituto de Geociências, UNICAMP. Campinas, agosto.

FORJAZ, M. C. S. (2005), As origens da Embraer. *Tempo Social, revista de sociologia da USP*, v. 17, p. 281-298, junho.

FREEMAN, C. (1995) The "National System of Innovation" in historical perspective. *Cambridge Journal of Economics*, v. 19, n. 1.

FREEMAN, C. (1999) Innovation systems: city-state, national, continental and sub-regional. In: CASSIOLATO, J.; LASTRES, H. *Globalização e inovação localizada*. Brasília: IBICT, pp. 109-167.

FREYRE, G. (1990). *Sobrados e mucambos*. 12a. edição. Rio de Janeiro: Record (2000).

FURTADO, C. (1982). *Análise do "modelo" brasileiro*. Rio de Janeiro: Civilização Brasileira, 8ª. Edição (1986).

FURTADO, C. (1987). Underdevelopment: to conform or to reform. In: MEIER, G. (ed) *Pioneers of development*. Second Series. Oxford: Oxford University/World Bank.

HOLANDA, S. B. (1991) *Raízes do Brasil*. 23ª ed. Rio de Janeiro: José Olympio.

KLEVORICK, A.; LEVIN, R.; NELSON, R.; WINTER, S (1995). On the sources and significance of inter-industry differences in technological opportunities. *Research Policy*, v. 24, p. 185-205.

MADDISON, A. (2001) *The world economy*: a millennial perspective. Paris: OECD.

MAZZOLENI, R.; NELSON, R. (2007) The Roles of Research at Universities and Public Labs in Economic Catch-up. *Research Policy*, v. 36, n. 10, pp. 1512-1528.

MOKYR, J. (1990) *The lever of riches*: technological creativity and economic progress. Oxford: Oxford University Press.

MOREL, C. (1999) Chagas' disease, from discovery to control – and beyond. *Memárias do Instituto Osvaldo Cruz*, v. 94, Sup. I, pp. 3-16.

MOTOYAMA, S. (Organizador, 2004) *Prelúdio para uma história*: ciência e tecnologia no Brasil. São Paulo: Edusp/Fapesp.

NARIN, F.; HAMILTON, K. S.; OLIVASTRO, D. (1997) The increasing linkage between U.S. technology and public science. *Research Policy*, v. 26, n. 3, pp. 317-330.

NELSON, R.; ROSENBERG, N. (1993) Technical innovation and national systems. In: NELSON, R. (Editor, 1993, p. 3-21).

NELSON, R. (Editor, 1993). *National innovation systems: a comparative analysis*. New York, Oxford: Oxford University Press.

NELSON, R.; ROSENBERG, N. (1994) American universities and technical advance. *Research Policy*, v. 23, pp. 323-348.

NELSON, R.; WRIGHT, G. (1992) The rise and fall of American technological leadership: the postwar era in historical perspective. *Journal of Economic Literature*, vol. 30, December.

NOVAIS, F. (1979) *Portugal e Brasil na Crise do Antigo Sistema Colonial* (1777-1808). São Paulo: HUCITEC.

O'SULLIVAN, M. (2004) Finance and innovation. In: FAGERBERG, J.; MOWERY, D.; NELSON, R. *Oxford handbook on innovation*. Oxford: Oxford.

OECD (2002) *Benchmarking industry-science relationships*. Paris: OECD.

PAULA, J. A. (1988) *Prometeu no Sertão: economia e sociedade na capitania das Minas dos Matos Gerais*. São Paulo: USP/Faculdade de Filosofia, Ciências e Letras (Tese de Doutorado em História).

PAULA E SILVA, E. M. (2007) A Experiência da Colaboração do Departamento de Engenharia Metalúrgica e de Materiais da UFMG com Empresas – lições para a Lei da Inovação. *Revista Brasileira de Inovação*, 6 (2), p. 433-459.

PELÁEZ, C. (1972) *Historia da industrialização brasileira* : critica a teoria estruturalista no Brasil. Rio de Janeiro: APEC.

PELÁEZ, C. M.; SUZIGAN, W. (1976) *História monetária do Brasil*: análise da política, comporamento e instituições monetárias. Rio de Janeiro: IPEA/INPES.

RAPINI. M. (2007) Interação Universidade-Empresa no Brasil: evidências do Diretório dos Grupos de Pesquisa no Brasil. *Estudos Econômicos*, v. 37, n. 2, pp. 212-233.

RAVETZ, J. R. (1990) The Copernican revolution. In: OLBY, R. C. *Companion to the history of modern science*. London: Routledge, pp. 201-216.

REALE, G.; ANTISERI, D. (1986) *História da filosofia*. São Paulo: Paulus (1990), volume II, pp. 185-322.

ROSENBERG, N. (1972) *Technology and American economic growth*. Armonk: M. E. Sharpe.

ROSENBERG, N. (1982) *Inside the black box*: technology and economics. Cambridge: Cambridge University.

ROSENBERG, N. (1991). Why do firms do basic research (with their money)? *Research Policy*, v.19: pp.165-174.

ROSENBERG, N. (2000) *Schumpeter and the endogeneity of technology*: some American perspectives. London: Routledge.

SALLES-FILHO, S. (Coord., 2000) *Ciência, Tecnologia e Inovação: reorganização da pesquisa pública no Brasil*. Campinas, Editora Komedi.

SANJAD, N. (2006) Emílio Goeldi (1859-1917) e a institucionalização das ciências naturais na Amazônia. *Revista Brasileira de Inovação*, 5 (2), p. 455-477).

SCHUMPETER, J. (1939) *Business cycles*: a theoretical, historical and statistical analysis of the capitalist process. Philadelphia: Porcupine, 1989.

SCHWARTZMAN, S. (1979) *Formação da comunidade científica no Brasil*. São Paulo: Nacional.

SCHWARZ, R. (1991) *Um mestre na periferia do capitalismo*: Machado de Assis. São Paulo: Duas Cidades, 2ª ed.

STEPAN, N. (1976) *Beginnings of Brazilian science*: Osvaldo Cruz, medical research and policy, 1890-1920. New York: Science History Publications.

SUZIGAN, W. (2000) *Indústria brasileira*: *origem e desenvolvimento*. São Paulo: Hucitec.

SYLLA, R. (1982) Monetary innovation in América. *Journal of Economic History*, v. XLII, n. 1; pp. 21-30.

SZMRECSÁNYI, T. (2000) Por uma história econômica da ciência e da tecnologia. *Economia Aplicada*, v. 4, n. 2, pp. 399-407.

VIOTTI, E.; MACEDO, M. M. (orgs) (2003) *Indicadores de ciência, tecnologia e inovação no Brasil*. Campinas: Editora Unicamp.